RU-643

Rec in BEE 12/12/85 RHM

Northwest and Alaska Fisheries Center

National Marine Fisheries Service

U.S. DEPARTMENT OF COMMERCE

NWAFC PROCESSED REPORT 85-19

Evaluation of the Effects of Oil Development on the Commercial Fisheries in the Eastern Bering Sea

October 1985

[redacted]

EVALUATION OF THE EFFECTS OF OIL DEVELOPMENT

ON THE COMMERCIAL FISHERIFS

IN THE EASTERN BERING SEA

(Summary Report)

T. Laevastu and R. Marasco
Project Leaders, and

N. Bax[1/], R. Fredin[2/], F. Fukuhara[2/], A. Gallagher, T. Honkalehto[1/], J. Ingraham, P. Livingston, R. Miyahara, and N. Pola-Swan

Resource Ecology and Fisheries Management Division
Northwest and Alaska Fisheries Center, Seattle, WA 98115
and
1/ Compass Systems Inc.
2/ University of Washington and
Natural. Resource Consultants

Final Report to RU 643
National Ocean Service
Office of Oceanography and Marine Services
Anchorage, Alaska

Resource Ecology and Fisheries Management Division
Northwest and Alaska Fisheries Center
Building 4, BIN C15700
7600 Sand Point Way N.E.
Seattle, WA 98115

ACKNOWLEDGEMENTS

"This study was funded wholly by the Minerals Management Service, Department of the Interior, through an Interagency Agreement with the National Oceanic and Atmospheric Administration, Department of Commerce, as part of the Alaska Outer Continental Shelf Environmental Assessment Program."

This is an advance copy of the "Final Report." Minor editorial changes have been made to the report with concurrence of the National Oceanic and Atmospheric Administration Contracting Officerrs Technical Representative (COTR). The "Final Report" is being processed through the NOAA-Outer Continental Shelf Environmental Assessment Program editing and publishing system and should be available in the near future.

CONTENTS

LIST OF TABLES AND FIGURES

pelagic fish species from a model run with no migration (solid line), and with migrations of 5, 10, and 15 km/day. Migration directions are shown.

1. PROBLEMS OF OIL DEVELOPMENTS AND FISHERIES INTERACTIONS

1.1 Problems pertaining to the effects of oil developments on the fisheries.

Some past oil spills from grounded tankers have caused extensive damage to beaches and have damaged local inter- and subtidal marine ecosystems. These coastal spills have received considerable attention in the news media and from the scientific community. However, no evidence has been found documenting noticeable detrimental effects of past oil developments on fishery resources (excluding minor local impacts), despite many Draconian forecasts of the possible impacts of oil developments on marine fisheries and ecosystems. Many of these sinister forecasts appear to have resulted from incorrect extrapolations of selective laboratory observations on the effects of hydrocarbons on the physiology, genetics, and mortality of fish (Payne 1982). As a result of misconceptions of possible effects of oil developments on marine ecosystems, an antagonistic attitude between oil development and fisheries prevails in the United States, whereas in Europe and in eastern Canada a cooperative attitude exists which is based on multiple-use concepts of natural resources.

To clarify the possible effects of offshore oil development on fisheries, it is necessary to investigate this complex of problems quantitatively (numerically) using all available pertinent knowledge. A contract to this effect was given from Mineral Management Service via National Ocean Service to the Northwest and Alaska Fisheries Center. The present report presents the summary of the studies of the possible effects of oil developments on the fishery resources in the eastern Bering Sea, mainly in Bristol Bay.

I. PROBLEMS OF OIL DEVELOPMENTS AND FISHERIES INTERACTIONS

1.2 Hypotheses on the probable effects of oil development on fisheries and fishery resources.

A main detrimental effect of local oil development on a fishery and its resources might be caused by an oil spill from a well blowout or from a pipeline rupture. On the other hand, an oil spill from a tanker accident may occur anywhere in the world where oil is transported.

Oil spills at sea spread at the surface, from where the greatest part evaporates, and the remainder dissipates through the water column by dissolution and emulsification. Weathered oil settles to the bottom, and if the accident happens near the coast, some of the oil might be blown to the shore. (This latter aspect is not considered in this study.)

If considerable concentrations of oil were to be found in the water column (dissolved and/or emulsified), it might have some lethal and sublethal effects on organisms (e.g. fish), before the natural oil-weathering processes restore the environment to pre-spill conditions (a matter of weeks) . Sedimentized weathered oil on the bottom will, however, persist longer than in the water column, and may have some effect on benthic animals (including demersal fish) for a longer period.

It has been assumed in the past that some direct (and immediate) effects of an oil spill on fishing might be:

1) Loss of fishing area, due to presumption by the spill or cleanup activity (see Section 4.3).

2) Possibility of fouling of vessels or gear (a discounted possibility of extreme rarity).

3) Inability to sell catch due to tainting (see Sections 4.2 and 4.3). (Possible consumer avoidance, often intensified by journalistic sensationalism.)

4) Possible loss of catch, due to toxic mortality of exploitable stock, or of eggs and larvae affecting future exploitable stock (see Sections 4.1, 4.2, and 4.4).

5) Acute but latent mortality to eggs, larvae, juveniles, and adults (see Sections 4.1, 4.2, and 4.4).

6) Effects on habitat and alteration of prey population and food chain (see Section 4.2).

Although possible genetic mutations are mentioned in some literature, no serious scientific evidence can be found to elaborate on this very remote hypothesis.

Many other factors besides possible oil-spill effects operate on fishery resources such as--year to year differences in availability of fish in given locations, natural fluctuations of stocks, effects of fishing on stocks, and market conditions. The effects of all factors affecting fish stocks can be evaluated on a comparative basis (i.e., comparing the oil-spill effects to natural fluctuations and to the local effects of resource changes on the fishery as a whole).

1.3 Objectives of present study.

The potential impacts of oil development on fisheries can be assessed with the present state of knowledge of complex dynamic, biological processes of stock production and ecosystem interactions, which can be attacked with complex marine fish ecosystem. simulations.

The present study addressed three major areas of possible impacts of oil on fisheries:

1) Effects of oil (from accidents) on fish and shellfish eggs and larvae, and the projection of these effects over subsequent years.

2) Possible effects of oil on adult fish. (including crabs and migrating salmon), and the possible uptake of hydrocarbons by fish (re: tainting and possible area closure in case of accidents).

3) Possible effects of weathered oil on the bottom on the benthic ecosystem (including demersal fish).

Two subjects received perfunctory consideration because the terms of the contract excluded them: the possible effects of oil on the. beaches; and the problems of possible effects of oil on marine mammals and birds.

The numerical study was carried out with hypothetical well blowouts and tanker accidents (Table 1) with the objective of achieving Maximum Effect Conditions (MEC), which was defined as follows (see also Table 1):

1) Either the largest plausible well blowouts in one of three locations (see Fig. 1), releasing 20,000 bbl/day of Prudhoe Bay crude oil for 15 days, or a tanker accident releasing 240,000 bbl automotive diesel (refined) at a rate of 10,000 bbl/hr in one of the same three locations: (1) off Port Moller, 45 m depth; 2) off Port Heiden, 43 m depth; and 3) off Cape Newenham, 43 m depth).

2) The spreading of oil in the water occurred in conditions of winds, tides, mixed layer depth, and temperature which produced the largest possible area of highest possible concentration (greater than 1 ppm) of water soluble fraction (WSF) of oil in the water. The wind direction chosen was the most frequent for the location.

3) The blowout/accident occurred during the most unfavorable time with respect to the fishery resources (peak spawning time with maximum aggregation of fish per unit area, and/or peak migration time of anadromous fish).

Table 1.--Hypothetical oil-spill scenarios.

Scenario	Oil type	Volume	Duration	Computation grid size (mesh 2 km)
Blowout	Prudhoe Bay crude	20,000 bbl/day	15 days	50 x 50
Accident	Automotive diesel (refined)	240,000 bbl (10,000 bbl/hr)	10 days	32 x 34

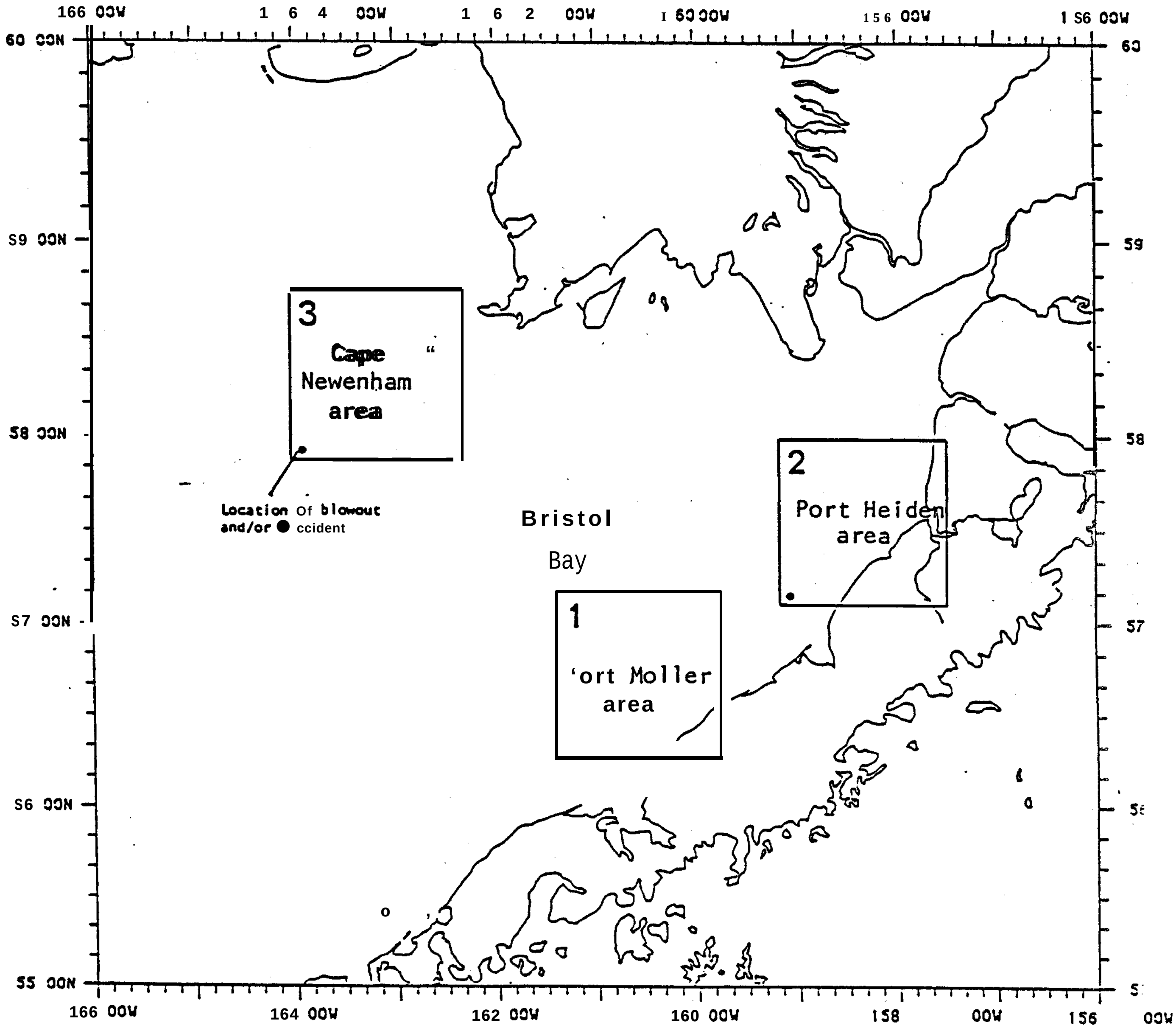

Figure 1 ---Locations of hypothetical oil spill scenarios.

4) The prevailing conditions affecting the sedimentation of the oil to the bottom were such that highest possible quantity of oil accumulated on the bottom in the shortest possible time.

Detailed results of the study are found in 15 technical reports (see Section 5); this report presents the summary of the essential results.

2. REVIEW OF PAST RESEARCH AND ITS APPLICABILITY.

2.1 Interpretation of laboratory research.

A voluminous amount of literature is available on the laboratory studies of oil effects on fish and other aquatic biota. The corresponding reports on field studies are few, and are mostly qualitative, inconclusive descriptions of past accidents. Some summary works on the subjectarealso available (e.g. Connell and Miller 1980, and U.S. National Academy of Science [(numerous authors)] 1984). Objective quantitative evaluation of the laboratory studies and their applicability to the "real world" is difficult indeed, and one has to agree with the conclusion of the National Academy of' Science report (1984):

"The single most significant gap existing to date is our difficulty in transferring the information obtained from laboratory studies to predicting and/or evaluating potential impact of petroleum on living marine resources in the field, especially in the case of oil spill impact on such commercially important stocks as fish and shellfish."

Principal problems with the evaluation of the past-effect studies are:

1) Most of the laboratory studies have been carried out with WSF concentrations two to four orders of magnitudes (100 to 10,000 times) higher than would occur in the ocean with the greatest plausible accident.

2) Numerous different components of hydrocarbons have been used in these studies, with very different methods of exposure to fish and other marine organisms.

Only rarely does some report state realistically the applicability of their results, as has been done by Duval and Fink 1981:

"Hydrocarbon levels in water following oil spills would rarely persist at the concentrations required to cause many of the physiological and behavioral effects observed during this investigation."

Studies of sublethal effects of petroleum hydrocarbons have also been summarized by Connell and Miller, op. cit., Nat. Acad. Sci. (op. cit.) and by Malins et al. 1982.

The essential applicable conclusion from the numerous past studies is that WSF concentrations in excess of 100 ppb are lethal to fish eggs and larvae within a few days, and that adult fish tolerate concentrations in excess of 1 ppm. The latter concentration can be taken as lowest limit of WSF concentrations which cause mortalities in fish within a few days.

The same concentrations (1 ppm) can be taken as the lower limit which causes sublethal effects in adult fish. The latter are often ill-defined; pathological changes in the liver of flatfish, for example, occur both in oil-exposed and non-exposed fish (Malins et al. 1982).

Most marine animals (including fish) are capable of metabolizing hydrocarbons. Metabolic products are usually retained longer in the bodies than parent hydrocarbons. Most of the hydrocarbons are taken up with food (especially benthos). It was concluded from the literature review that fish can be considered tainted if the concentration of hydrocarbons in the body is 5 ppm. Hydrocarbons can be present in fish even when no tainting is detected (Crahl-Nielsen, Neppelberg, Palmork, Westrheim, and Wilhelmsen 1976).

2.2 Past experiences with oil spills pertaining to fisheries.

Frequent remarks on possible effects of oil spills on fish and fisheries can be found in existing "oil spill literature." These unquantified remarks are, however, unsubstantiated in the majority of cases. Only five reports (summarized below) attempt to evaluate quantitatively the possible effects of oil developments and oil spills on fisheries. In addition, there exists a few good local studies on the subject which cover (and emphasize) the socio-economic aspects of oil developments on local fishing communities (e.g. Canadian studies from Newfoundland and Nova Scotia).

Ar. earlier study by Johnston (1977) concludes that losses reckoned as fish production or its approximate cash equivalent are very small even for a catastrophic oil spill. Another study by Norwegian scientists (Norges Offentlige Utredninger NOU 1980:25) points out that the main effect of an oil spill on fish resources is via the effects of oil on fish eggs and larvae. These *effects* would be delayed several years and entirely masked by natural fluctuations of recruitment, and compensated by the presence of several year classes of fish in exploitable parts of the stocks.

Davenport (1982) reported that field studies have revealed no lasting damage to the planktonic ecosystem (one of the food sources for fish) caused by oil. Conan (1982) described that in case of catastrophic oil spills reaching estuaries (Amoco Cadiz spill), the estuarine benthos was affected by oil (see further details in Laevastu and Fukuhara 1985, ref. 7 in Section 5), whereas the resident fishes (flatfishes and mullets) were affected *to* a minor degree (possible reduced growth and fecundity, and some fin rot).

A thorough examination of the oil pollution and fisheries by McIntyre (1982) concludes that no long-term adverse effects on fish stocks can be attributed to oil. There might however, be some local impacts, such as in estuaries as reported by Conan (op. cit.).

The results reported in this summary are the very first attempts to comprehensively estimate the possible adverse effects to the eastern Bering Sea environment and biota caused by spills of petroleum of specified composition and volume at designated. spill sites. The list of the reports resulting from this study is presented in Section 5.

3. METHODS AND DATA USED IN PRESENT STUDY

3.1 Numerical methods.

3.1.1 Oil in the water.

The computations of the distribution of oil from the three sites of hypothetical well blowouts and tanker accidents (see Section 1.2 and Fig. 1) were carried out by Rand Corporation (Liu and Pelton 1984MS, Mannen and Pelto 1984). The dissolution and dispersion of oil in the water was based on studies by Payne, Kirsten, McNabb, Lambach, de Olivera, Jordan, and Horn 1983; and Payne and Kirsten 1985MS.

The presence and distribution of oil on the surface in offshore areas has no consequences to fish or fisheries. Any area closure for fishing will be determined by the area where contaminated fish can be found, which is considerably larger than the oil distribution area on the surface (see Section 4.3). Obviously in some conditions oil on the surface could be beached, where it will be of local concern. Although some marine birds and mammals could be affected (and killed) by surface oil, these kills are relatively small in offshore waters (most birds and mammals have avoidance reactions), compared to the great amounts of birds and mammals present in the Bering Sea. Some fisheries interests consider it beneficial for fisheries if the bird and mammal populations are reduced.

The maximum concentrations of oil in water (WSF, including soluble and emulsified oil) was less than 0.34 ppm from the blowout scenarios. These low concentrations correspond well tc observed concentrations from IXTOC blowout. Grahl-Nielsen et al. (1976) also observed low concentrations of oil under the oil slick (0.450 ppm 1 m under oil slick after 8 to 9 hours; 0.01 ppm after 24 hours) . An example of distribution of oil from a blowout scenario is shown in Figure 2.

The maximum concentrations from the "tanker accident" were higher than (ca 9 ppm), mainly because refined diesel oil *was* considered to be involved. The areas covered by different concentrations are reported by Pola-Swan, Miyahara, and Gallagher 1985 (see ref. 10, Section 5).

3.1.2 <u>Oil on the bottom</u>.

After "weathering" in the water, much of the residual oil precipitates to the bottom. Gearing and Gearing (1983) found that about 50% of aromatics with three or more rings and saturates with 10 or more carbon atoms were rapidly transported to the sediments where their half-lives ranged from 33 to 80 days. In shallow water the concentration of oil in muddy bottoms might reach 100 ppm (Marchand, Capris 1982).

The available literature on the sedimentation of oil and the effects of oil on the bottom on the benthos and demersal fish was reviewed, and a numerical model for sedimentation of oil was designed (Laevastu and Fukuhara 1985) . This model accounts quantitatively for all factors affecting the oil sedimentation (see example in Figure 3).

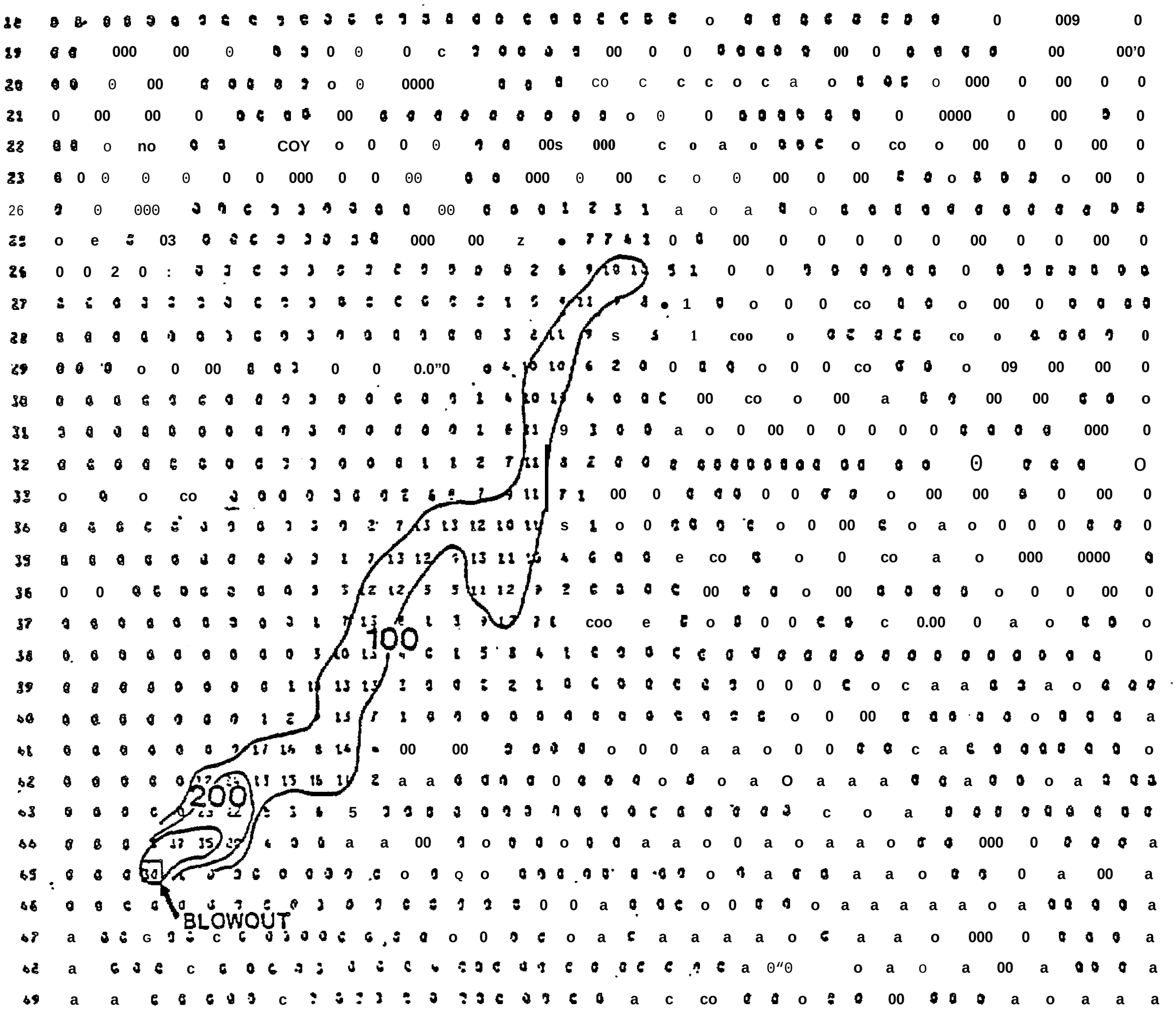

Figure 2.--Distribution of oil from a blow-out (20,000 bbl/day) after 10 days (concentrations in ppb in water - from surface to 15 m; grid mesh size 2 km).

Initially the weathered sedimentized oil accumulates in the near-bottom nepheloid layer. The existence and thickness of this layer is dependent on several environmental factors, such as water depth, nature of the bottom, and water movement over the bottom.

Weathered oil is no longer directly poisonous to organisms and is taken up by benthos and via benthic food, also by fish, causing tainting in fish. These tainting effects by sedimentized oil are considerably larger than the tainting from WSF of oil. Tainting is a temporary condition, as most petroleum hydrocarbons are removed from the body by various means (see Gallagher and Pola-Swan 1984, ref. 5, Section 5). The main effects of tainting would be a necessary area closure for fisheries (see Section 4.3).

3.1.3 Uptake and deputation of petroleum hydrocarbons by fish.

After an extensive review of literature on uptake and dissemination of petroleum hydrocarbons a numerical model was designed which accounts for uptake, bioaccumulation, and dissemination of petroleum hydrocarbons , (Gallagher and Pola-Swan 1984, Pola-Swan 1984, and Gallagher 1984, refs. 5, 3, 4 in Section 5). This model accounts for species differences due to, e.g., feeding habits by assigning different uptake and deputation rate constants to different species. The model was tested via sensitivity analyses with the best available empirical data.

Another companion model moves the fish through the oil-contaminated area in various directions and with selected plausible fish migration speeds. During the migrations the uptake and depuration model computes the contamina-

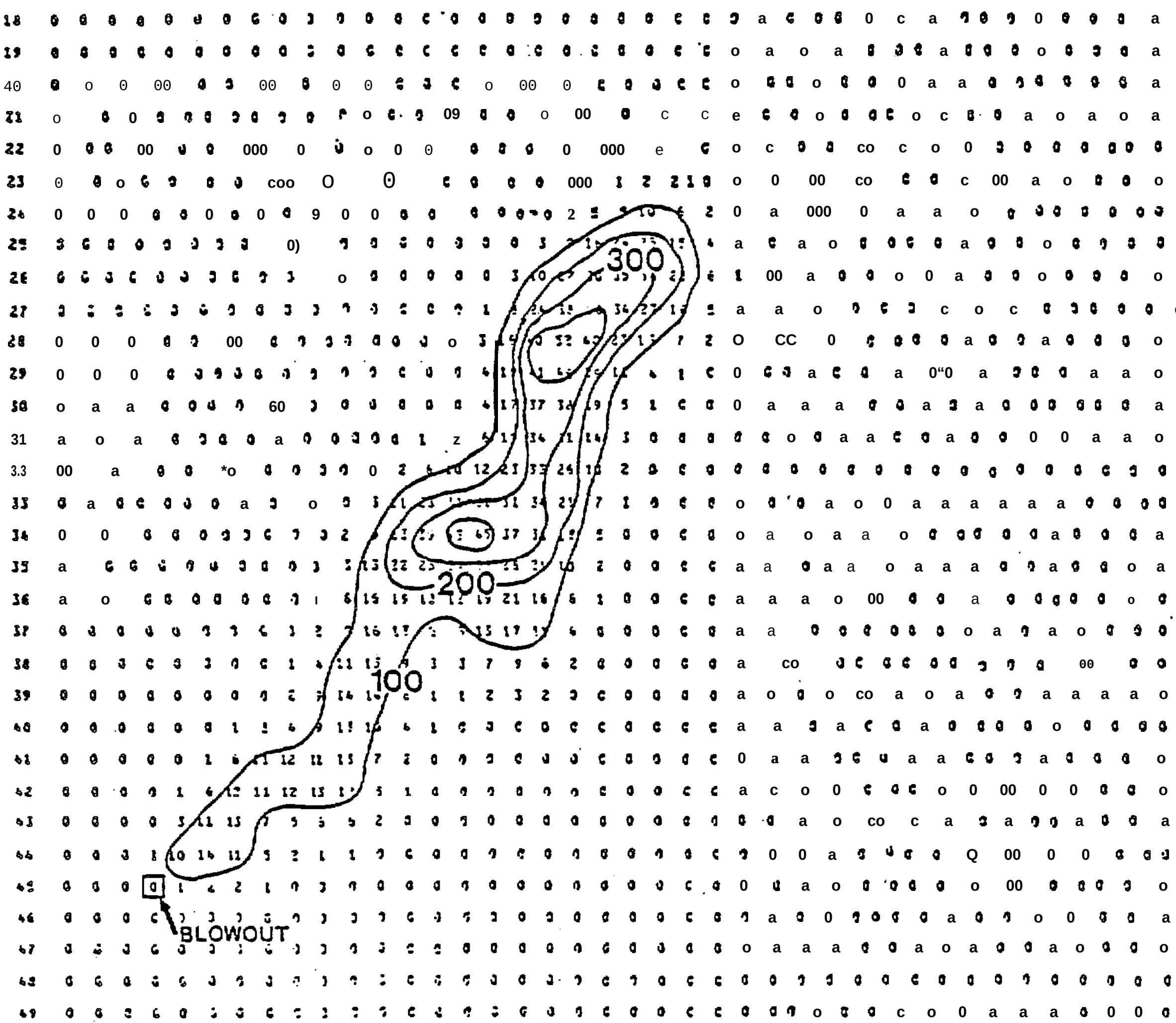

Figure 3 --Distribution of oil in the bottom nepheloid layer (10 cm) in ppb 10 days after a well blowout (see Figure 2); grid size 2 km).

tion of fish by hydrocarbons. Thus the areas and times of possible fishery closure resulting from a given accident can be assessed {see Section 4.3).

As the anadromous fish (salmon) pose somewhat different problems, a special model was devised for computing possible oil contamination effects on migrating salmon (smolts and adults) (Bax 1985, ref. 8 in Section 5) (results see Section 4.4).

3.2 Data

3.2.1 Environmental data pertaining to oil development - fisheries interactions.

Few environmental data are required for the evaluation of the effects of oil development on fisheries. The distribution of oil in the water and on the bottom was computed with wind and tide conditions which gave maximum concentrations of oii in the water and on the bottom. For computation of oil on the bottom optimum suspended matter load, bottom type, and mixed layer depth was assumed which would give MEC conditions. Some other environmental data are location and season dependent. The essential environmental data were summarized by Miayahara and Ingraham 1984 (ref. 6 in Section 5?.

3.2.2 Fishery resources, their fluctuations, and fish species which might be affected by an oil spill.

The fishery resources in the eastern Bering Sea are mobile, with extensive seasonal and life-cycle migrations. Thus the total Bering Sea resources and their seasonal distributions must be considered while investigating the effects of oil development. Furthermore, the natural fluctuations of the stocks must be taken into consideration, together with many species' specific behaviors.

The resource estimates, using presently existing survey methods, are rather inaccurate, usually gross underestimates, but also overestimates in case of some flatfishes (i.e., "herding" effects of trawls). Resource evaluation with ecosystem-simulation models, which account for a number of resource determinants, produces considerably more accurate results and has been used in the present study.

A list of species and their densities (kg/km^2) used in the three oil-spill scenario areas (Figure 1) is given in Table 2. Table 3 gives the species present in the three computation areas as percentage of total Bering Sea biomasses of corresponding species. The feeding habits of the species under consideration have been described by Livingston 1985 (ref. 12, Section 5). In addition, the biology and ecology of the most important commercial species in the area have been summarized by Fredin 1985, Fukuhara 1985a and 1985b (refs. 9, 13, and 15, Section 5). Pertinent biology, ecology, and resource fluctuations data on sockeye salmon have been summarized by Bax 1985 (ref. 8, Section 5).

Of some pertinence to the evaluation of the oil-development impacts might be the following generalized data. The Bristol Bay area (where oil development might occur) is *ca* 250,000 km and the rest of the fishery area in the Bering Sea is about 400,000 km^2. However, at some defined seasons Bristol Bay

Table 2--List of species and input biomass data (by location) used in BIOS[1/] model.

No.	Species Name	Input Biomass Data (kg/km²) [2/]		
		Port Moller	Port Heiden	Cape Newenham
1	Herring juveniles	1409	521	1551
2	Herring adults	1121	414	1234
3	Pollock juveniles	3708	2322	3261
4	Pollock adults	11007	6893	9679
5	Pacific cod juveniles	424	279	307
6	Halibut juveniles	730	330	240
7	Yellowfin sole juveniles	722	482	711
8	Other flatfish juveniles	2004	1472	1650
9	Yellowfin sole adults	800	534	789
10	Other flatfish adults	2004	1472	1650
11	Pacific cod adults	861	461	681
12	King and Bairdi crab juveniles	664	222	432
13	King and Bairdi crab adults	1654	553	1078
14	Mobile epifauna	5970	4995	6075
15	Sessile epifauna	13930	11655	14175
16	Infauna	19150	13750	19250

1/ The DYNUMES model (Laevastu and Larkins, 1981) was used to get initial estimates of input biomass data for the three model locations of the BIOS model.

2/ The following assumptions were used to convert the data obtained from the DYNUMES model to biomass fields for use in the BIOS model.

a) Unless noted differently below, the breakdown of species biomass data into juvenile and adult fractions was based on Niggol (1982).

b) DYNUMES species group 5 (halibut) was assumed to be 100% juvenile (i.e., in these shallow waters during this season).

c) Yellowfin sole data were assumed to comprise 75% of DYNUMES species group 7 (yellowfin and rock sole).

d) DYNUMES species group 13 (Pacific and saffron cod) was assumed to be 100% Pacific cod.

e) DYNUMES species groups 7 (rock sole-25%), 6 (flathead sole, flounder), and 8 (other flatfish) were combined to make up the other flatfish group (species 8 and 9) for the BIOS model. These groups were assumed to be equally divided between juveniles and adults.

f) DYNUMES species groups 19 (king crab) and 20 (Tanner crab) were combined, and using available survey data, assumed to be comprised of 71.4% adults and 28.6% juveniles.

g) DYNUMES species group 24 (epifauna) was assumed to be 30% mobile and 70% sessile.

Table 3.--Percent of Bering Sea biomass (from DYNUMES model) in blowout and accident scenario study areas.

Species (group)		Location: Pt. Moller	Pt. Heiden	C. Newenham
1	Herring, juveniles	0.505	0.187	0.556
2	Herring, adults	0.505	0.187	0.556
3	Pollock, juveniles	0.471	0.295	0.414
4	Pollock, adults	0.471	0.295	0.414
5	Pacific cod, juveniles	0.577	0.379	0.418
6	Halibut, juveniles	1.220	0.551	0.401
7	Yellowfin sole, juveniles	0.902	0.602	0.888
8	Other flatfish, juveniles	1.141	0.838	0.939
9	Yellowfin sole, adults	0.900	0.601	0.888
10	Other flatfish, adults	1.141	0.838	0.939
11	Pacific cod, adults	0.577	0.309	0.456
12	King and Bairdi crab, juveniles	0.806	0.269	0.524
13	King and Bairdi crab, adults	0.804	0.268	0.524
14	Mobile epifauna	0.416	0.348	0.424
15	Sessile epifauna	0.416	0.348	0.424
16	Infauna	0.604	0.433	0.607

might contain about 80% of crab resources, 70% of herring, 70% of yellowfin and halibut, 60% of cod, and 50% of other fish resources of the Bering Sea. These high percentages do not, however, occur at the same time.

4. RESULTS OF QUANTITATIVE EVALUATION OF FISHERIES - OIL DEVELOPMENT INTERACTIONS.

4.1 Possible effects on eggs and larvae.

Eggs and larvae of marine animals are most sensitive to dissolved and emulsified oil (WSF) in tbe water. The mortalities and serious sublethal effects start at concentration of ca 100 ppb.

The areas covered with WSF greater than a part per billion are relatively small in case of a substantial blowout 'lasting 15 days (less than 150 km^2, Table 4). Even in case of such an unlikely event as 200,000 barrel tanker accident with diesel fuel (released almost instantaneously), the area covered by this concentration is less than 1200 km^2 (Table 4).

Most marine fish spawn over relatively large areas, and the pelagic eggs and larvae are distributed with currents and turbulence over very large areas. Furthermore, the spawning of most marine fish lasts three to six months, with peak spawning lasting also in excess of three weeks.

Of the species studied, the spawning of yellowfin sole and its eggs and larvae were found most affected by the simulated blowout and tanker accidents in Bristol Bay. (Coastal spawning of herring and capelin was not considered

Table 4.--Maximum spatial coverage (km*) and maximum duration (days) of various levels of oil in water (WSF) and in bottom' nepheloid layer (TARS) at different concentrations at Port Heiden.

Oil cone. (ppm)	Accident				B 10WOU t			
	WSF		TARS		WSF		TARS	
	area	duration	area	duration	area	duration	area	duration
>1.0	380	13	752	3 3	0	0	0	0
>0.1	1160	21	1548	>50	132	12	248	24
>0.01	1844	28	2140	>50	41,1,	20	460	43
>().001	2480	36	,2560	>50	616	27	652	>50

in this study and salmon is described in Section 4.4). If all yellowfin sole would spawn within two weeks and this spawning would coincide with the very unlikely tanker accident, only 1.2 percent of yellowfin eggs and larvae would be killed (Table 5). However, the yellowfin sole spawning period is about five times longer than that used for the simulated accident--thus, less than 0.3 percent of yellowfin eggs and larvae would be affected. The fraction of eggs and larvae of other fish species that would be killed is less than this fraction.

The natural mortality of fish eggs and larvae is very large (the reduction in numbers from eggs to spawning adults is in general from between 2,000,000 to 2, to 50,000 to 2). Furthermore, if considerable mortality would occur due to extensive oil spill, this would not affect the fishery resources, as the exploitable stocks are "buffered" by the presence of several year classes (Honkalehto 1985, ref. 11, Section 5). Consequently, the possible oil developments in Bristol Bay would have minimal effects on fishery resources in this area via effects on eggs and larvae. Similar conclusion was reached by Järvela, Thorsteinson, and Pelto (1984) in respect to Navarin Basin. Further detailed considerations on this subject are given in reports by Fredin (1985) and Fukuhara (1985a, b, ref. 9, 13 and 15 in Section 5).

4.2 Exposure and contamination of fish by hydrocarbons.

The lethal effects of WSF of oil on fish commence in the 1 to 10 ppm range. In present studies we have used the lower value (1 ppm) to achieve MEC (Maximum Effect Condition). The maximum areas covered with different ranges of concentrations (blowout and the unrealistically large tanker accident) are

Table 5.-- Estimated percentage of mortality from acute toxicity in yellowfin sole in the accident scenarios at Port Moller, Port Heiden and Cape Newenham by life history group and quarter.

A. Percentage Mortality at Port Moller or Port Heiden Spill Sites

QUARTERS	1		2		3		4	
STAGE	WSF	TARS	WSF	TARS	WSF	TARS	WSF	TARS
EGGS & LARVAE	o	0	0	0	0	0	0	0
JUVENILES	.03	.15	.03	.15	.03	.15	.03	.15
ADULTS	o	0	.03	.15	.03	.15	0	0

B. Percentage Mortality at Cape Newenham Spill Site

EGGS & LARVAE	o	0	0	0	1.2	0	0	0
JUVENILES	.03	.15	.03	.15	.03	.15	.03	.15 “
ADULTS	o	0	.03	*15	.03	.15	0	0

given in Table 4. In evaluating the effects (lethal and serious sublethal) we have also assumed that concentrations of weathered oil on the bottom (tars) in excess of 5 ppm affect the juvenile adult fish. This assumption is somewhat excessive according to available literature, but would given an absolute MEC.

Detailed computations were made with the models and results given in technical reports (see Section 5). For summary considerations we car use a simplified approach by considering data in Table 4 and Figure 4, with the data in Table 2 which gives the amounts of species present in the three computation areas (Figure 1), and the fraction of this biomass of the total species biomass in the eastern Bering Sea (Table 3) (most species have only one stock in this sea).

Of the species considered in this study, yellowfin sole and king crab were found to be most affected by the hypothetical oil spill (salmon see Section 4.4). A summary of the possible lethal effects of the spills on yellowfin sole are given in Table 5.

The extensive well blowout would kill and/or seriously affect only 0.03 percent of yellowfin (and crab) population in the eastern Bering Sea, which is nearly three orders of magnitude less than the accuracy of resource estimates. Thus an extensive blowout would riot have a measurable effect on offshore fishery resources in the eastern Bering Sea.

An unreasonably large tanker accident as used in our scenarios might kill or otherwise seriously affect 0.15 percent of the adult yellowfin population. This amount is about two orders of magnitude less than the accuracy cf re-

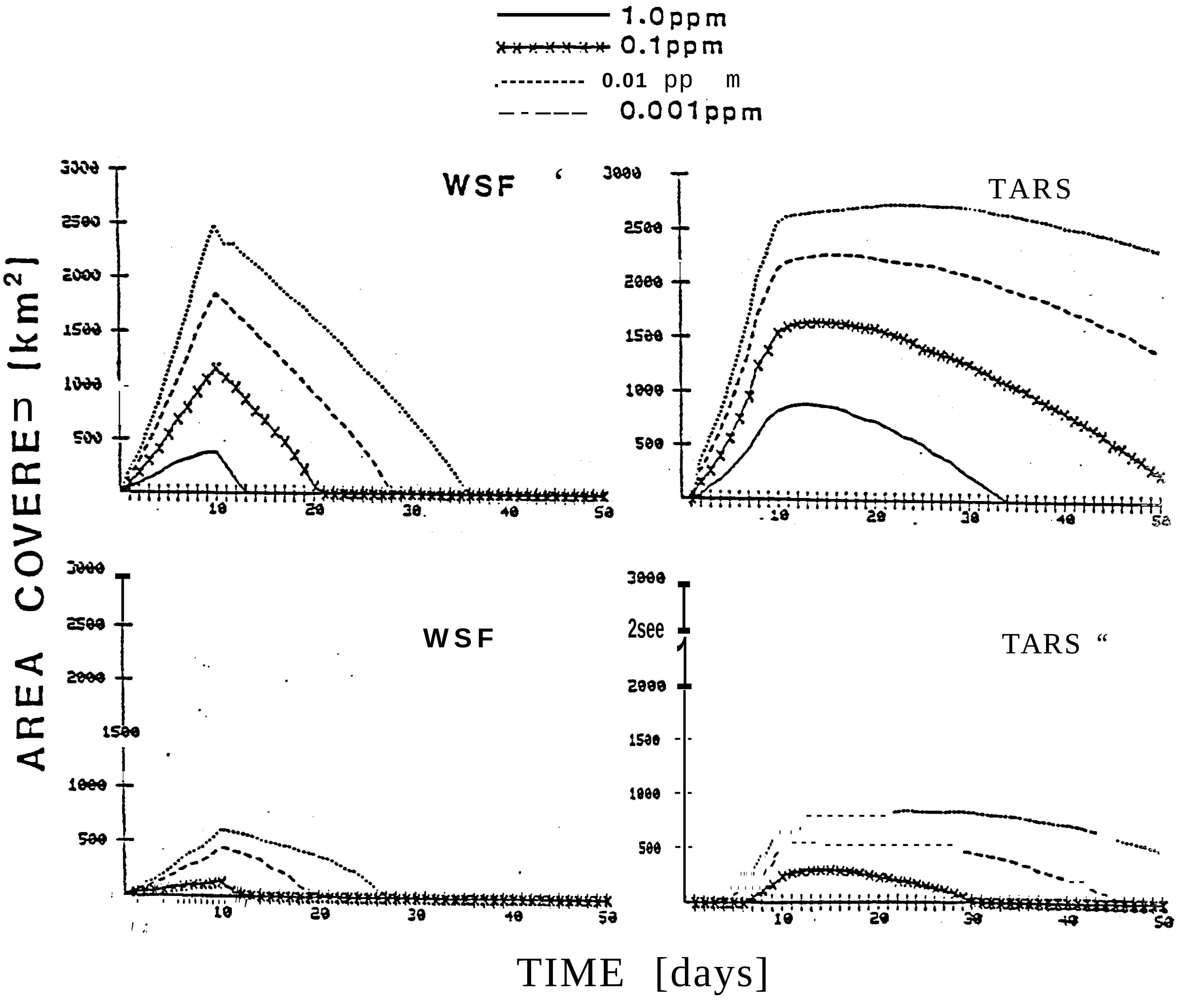

Figure 4.--Time series of total area covered (km^2) by WSF and by TARS at concentrations greater than 1.0 ppm, 0.1 ppm, 0.01 ppm, and 0.001 ppm for the accident (upper) and blowout (lower) scenarios.

source estimates, and at present less than 2 percent of the catch--i.e. about an order of magnitude less than the error in the estimation of catch. However, a 0.15 percent fluctuation of resource would have no effect on catch whatsoever. Thus, even an unreasonably large tanker accident would have no quantifiable effect on the offshore fishery resources in the eastern Bering Sea.

Fish can, however, be temporarily tainted with petroleum hydrocarbons by direct exposure as well as by food uptake of contaminated food, mainly benthos. The uptake of petroleum hydrocarbons and their dissemination with time was computed in detail with numerical models (Gallagher and Pola-Swan 1985; Pola-Swan, Miyahara, and Gallagher 1985; refs. 5 and 10 in Section 5). The percentage of some biomasses in the computation area with internal contamination of less than 5 ppm (lower level of tainting) is given in Figure 5. These values have meaning to fisheries in terms of areas covered, which are given in Table 6. These areas are significant in the case of the blowout and/or accident when they should be temporarily closed for fishing to prevent tainted fish from being caught and marketed.

4.3 Effects of possible precautionary measures in offshore areas during an accident.

The possibilities of contaminating fishing gear with oil is often mentioned when listing the possible effects of oil developments on fisheries. We cannot see this ever happening in Bristol Bay. There is very little set gear (e.g., traps, longlines) used in this area. If some gear would be in the vicinity of the accident, there would be ample time to remove it. Mobile fishing gear (e.g., trawls) cannot be contaminated with oil, unless it is done willfully.

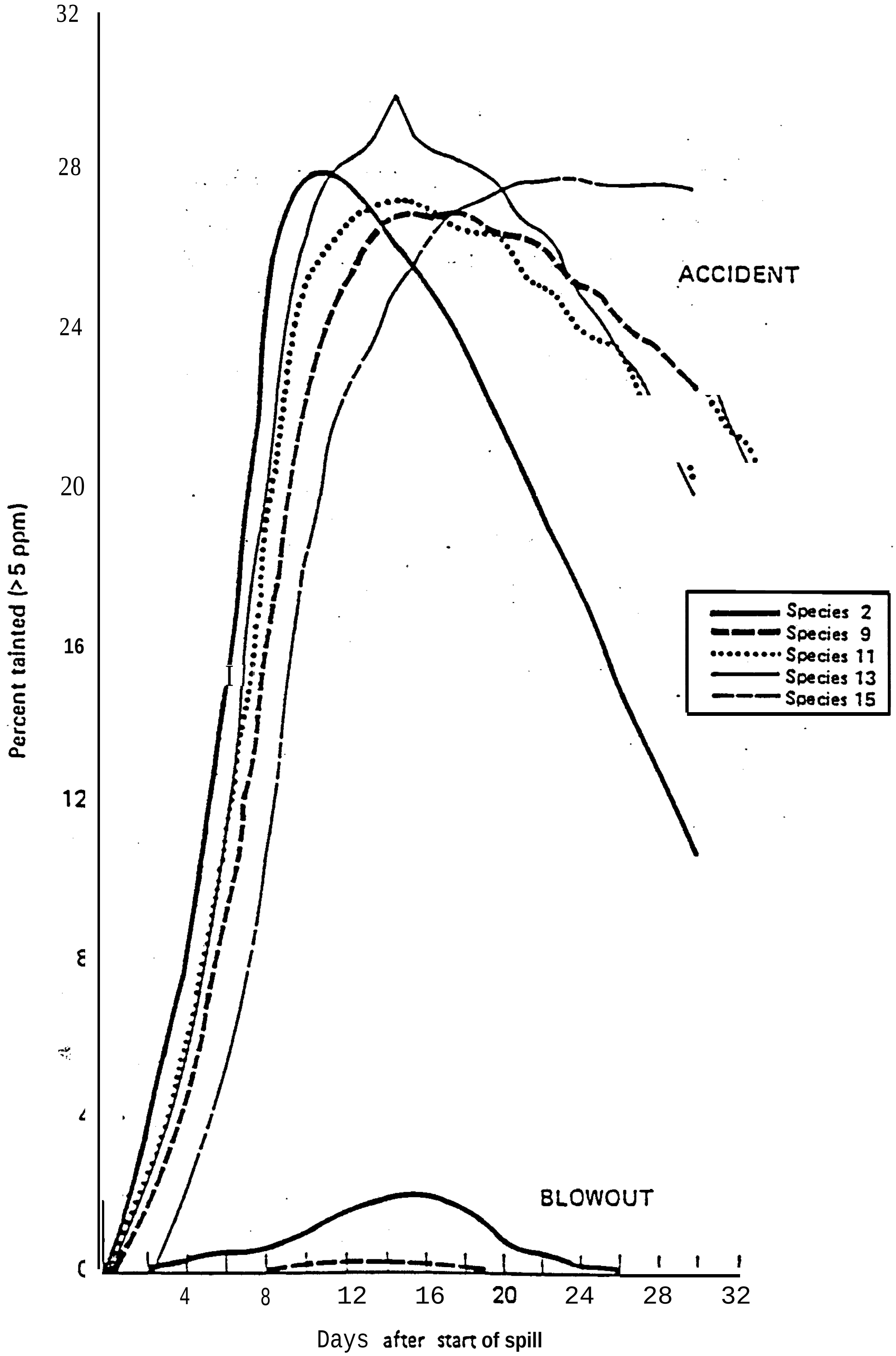

Figure 5.--percent of biomass of selected species within the BIOS model grid tainted in the accident and blowout scenarios.

Table 6---**Areas covered with herring juveniles (Species 1) and adult King and Bairdi crabs (Species 13) contaminated with petroleum hydrocarbons at various levels. (Time sequence in days; area covered in km^2.) No migrations. Port Heiden accident scenario.**

	Species 1				Species 13			
	Contamination (ppm)				Contamination (ppm)			
Day	>5	>10	>50	>100	>5	>10	>50	>100
1	72	56	24	4	24	8	0	0
2	144	120	60	32	80	52	0	0
3	240	208	96	48	144	96	0	0
4	356	292	140	80	"228	160	a	0
5	468	392	1?2	?6	320	232	40	0
6	616	512	248	116	424	324	6a	0
7	764	632	304	144	564	428	92	0
8	968	7?2	360	1 4a	736	5 4 4	124	0
9	1080	900	412	152	5'04	684	156	4
10	1212	988	452	168	1020	788	216	20
11	1224	1020	472	152	1108	86a	268	24
12	1232	1036	452	136	1144	920	2?2	32
13	1216	1012	424	104	1192	960	328	32
14	1188	?7.5	37.5	56	1228	976	356	32
15	1152	936	32a	20	1236	1000	364	2a
16	1100	880	268	0	1240	1008	368	20
17	1068	856	1 ?2	0	1240	1004	352	16
18	1036	792	116	0	1244	996	336	12
19	5'72	744	52	0	1240	976	320	a
20	?24	684	4	0	1220	?60	292	4
21	868	604	0	0	1188	952	272	0
22	820	552	0	0	1168	932	220	0
23	744	476	0	0	1152	916	196	0
24	68a	400	0.	0	1148	884	156	0
25	604	340	0	0	1128	860	112	0
26	540	24a	0	0	1104	832	80	0
27	472	152	0	0	1068	7E4	24	0
28	388	76	0	0	1040	760	0	0
29	324	8	0	0	1016	732	0	0
3 0	224	0	0	0	968	696	0	0
31	128	0	0	0	940	640	0	0
32	4a	0	0	0	904	592	0	0
33	o	Q	0	0	864	568	0	0
34	0	o	0	0	824	516	0	0
35	0	0	0	0	780	448	0	0
36	0	0	0	0	74a	412	. 0	0
37	0	0	0	0	6?2	372	0	0
38	0	0	0	0	648	304	0	0
39	0	0	0	0	588	248	0	0
40	o	0	0	0	54a	180	0	0
41	0	0	0	0	488	116	0	0
42	0	0	0	0	440	64	0	0
4 3	0	0	0	0	384	16	0	0
44	0	0	0	0	324	0	0	0
45	0	0	0	0	248	0	0	0
46	0	0	0	0	192	0	0	0
47	0	0	0	0	136	0	0	0
4a	0	o	0	0	92	0	0	0
49	0	0	0	0	28	0	0	0
50	0	0	0	0	" o	0	0	0

If an accident should happen (i.e., oil spilled in the water in considerable quantities), fishing in the affected area must stop for awhile in order to prevent the capture and marketing of fish tainted with oil. The tainting of fish and the area covered, and time period of tainting, was computed with our simulations (Pola, Miyahara, and Gallagher 1985, ref. 10 in Section 5). The maximum areas covered in the cases of well blowout and tanker accident are given in Table 6 for two typical species (juvenile herring and adult crabs). Figure 6 shows the development of these areas with time and the subsequent deputation. Both Table 6 and Figure 6 refer to the tanker accident which produces the largest effect.

The maximum area covered with tainted crabs is less than 1300 km^2. After 30 days the area has decreased to less than 1000 km^2 and after 50 days all fish and crab would be depurated below detectable level. The tainting from a well blowout *was* considerably less, covering less than a quarter of the above-mentioned areas.

In case of a very unlikely tanker accident (which might happen anywhere in the world), an area of about 2000 km^2 should be closed for fishing for about 45 days. Whether and how much *a* closure can affect fisheries is meaningless to evaluate quantitatively. First, the event is extremely rare. Secondly, it might happen in an area which is net a traditional fishing ground. Thirdly, the fishing areas (grounds) are of considerable extent (species and season dependent) and fishing might continue in other nearby areas with some profitability *as* it would have done in a closed area. (It could be noted that 2000 km^2 is less than 1% of the area of Bristol Bay, and equally less than 1% of the "prime" fishing grounds in the Bering Sea.)

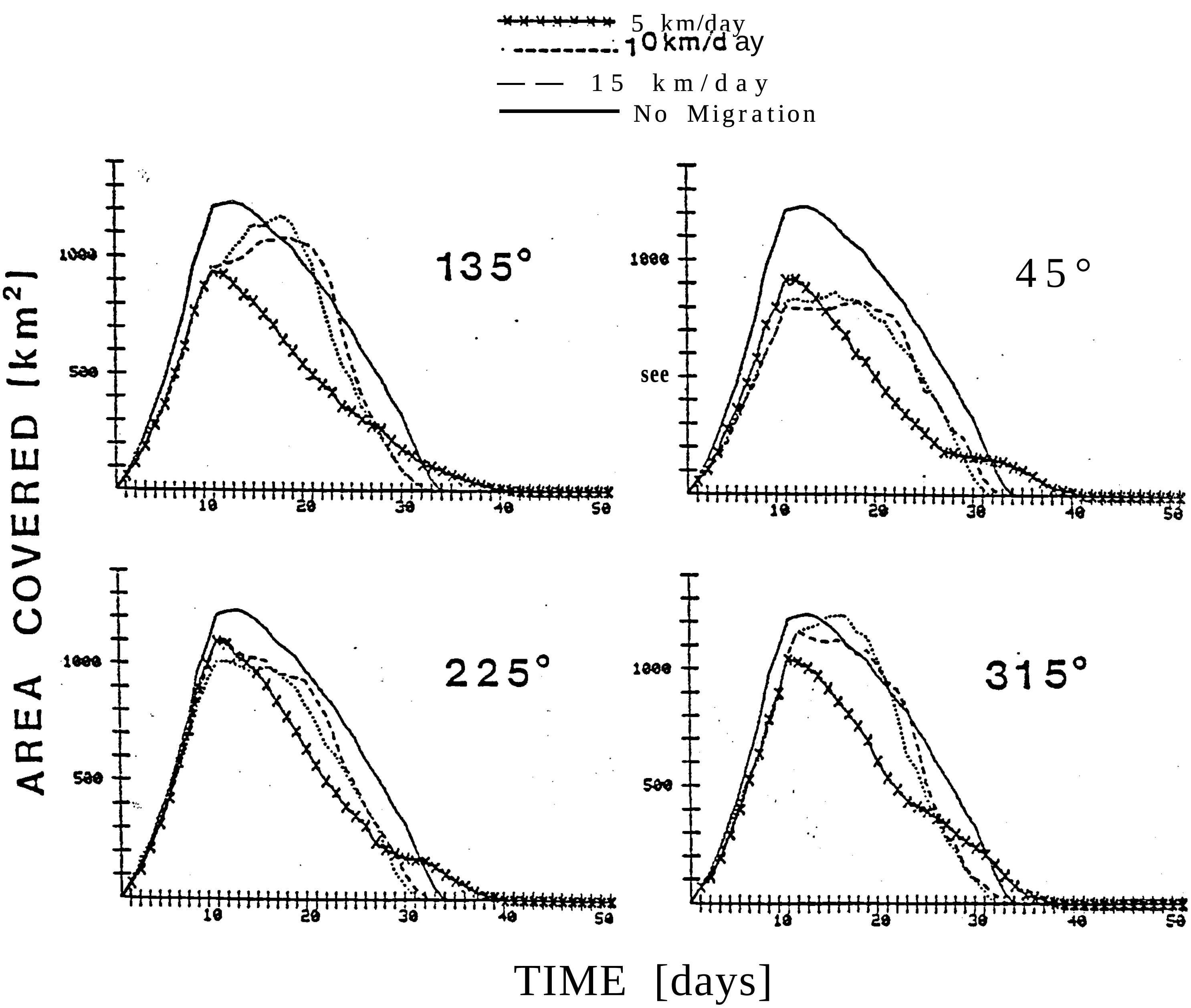

Figure 6.--Area covered by tainting (contamination >5 ppm) of a pelagic fish species from a model run with no migrations (solid line) and with **migrations of 5, 10, and 15 km/day. Migration directions** are shown.

4.4 Special considerations with anadromous fish.

Special, careful consideration of the possible effects of oil development on salmon is required due to its importance in Alaskan fisheries, and especially because of the possibility of the presence (and/or passage) of a great portion of outmigrating juveniles (smolt) and returning adults in possible oil spill sites. A thorough numerical study of possible effects of oil on sockeye salmon (the main species in Bristol Bay) was conducted within the three blowout and accident sites (Bax 1985, ref. 8, Section 5). The assumptions of oil effects in this study were more conservative than with marine fish to achieve MEC (100% mortality at 450 ppb of fuel oil in 24 h; 100% mortality at 2.5 ppm of crude oil in 24 h; tainting level in salmon flesh 600 ppb).

The computations of migrations of smelt (juveniles) and adults were carried out with no-avoidance and with avoidance reaction. The results of the effects of a blowout and/or tanker accident happening during the most unfavorable periods in Port Heiden and Port Moller areas are summarized in Tables 7 and 8 (considering only that portion of the populations passing through these areas at the accident time). The mortalities and tainting extrapolated to whole Bristol Bay sockeye population for the tanker accident is given in Table 9.

A maximum of 13% mortality of outmigrating smelt could be caused by unlikely tanker accident. This *does* not mean that the returning year class would be affected by the same amount, as the natural mortality of smelt is variable from year to year (on average 90%). It is unrealistic to quantify

Table T:':- Simulated percent mortalities of sockeye salmon migrating through the oil spill grids either directly or with avoidance of the spill.

Spill scenario	Run time (hrs)	Percent mortalities Direct migration	Migration with avoidance
Juveniles			
Port Heiden			
Tanker spill/fuel oil	240	35.5	15.4
Blowout/crude oil	480	0.4	0.5
Port Moller			
Tanker spill/fuel oil	240	14.2	7.0
Blowout/crude oil	480	1.2	0.5
Adults			
Port Heiden			
Tanker spill/fuel oil	240	17,6	3.2
Blowout/crude oil	480	0.2	0.1
Port Moller			
Tanker spill/fuel oil	240	11.6	2.1
Blowout/crude oil	480	O*2	0.1

Table 8--- Simulated percent taintings of sockeye salmon migrating through the oil spill grids either directly or with avoidance of the spill.

Spill scenario	Run time (hrs)	Percent tainted above 0.6 ppm	
		Direct migration	Migration with avoidance
Juveniles			
Port Heiden			
Tanker spill/fuel oil	240	17.7	10.6
Blowout/crude oil	480	0.0	0.0
Port Moller			
Tanker spill/fuel oil	240	5.2	3.1
Blowout/crude oil	480	0.1	0.0
Adults			
Port Heiden			
Tanker spill/fuel oil	240	7.1	3.1
Blowout/crude oil	480	0.0	O*O
Port Moller			
Tanker spill/fuel oil	240	5.0	2.6
Blowout/crude oil	480	0.0	0.0

Table 9.?- Percent mortalities and tainting from tanker spill scenarios extrapolated to whole population.

Age group	Location of spill	Reduction factor xx	Percent mortalities		Percent tainted	
			Direct	Avoid	Direct	Avoid
Juveniles I.[x] (combined rivers)	Pt. Heiden	0.36	12.8	5.5	6.4	3.8
	Pt. Moller	0.47	6.7	3.3	2.4	1.5
Juveniles 2.[x] (combined rivers)	Pt. Heiden	0.28	9.9	4.3	5.0	3.0
	Pt. Moller	0.36	5.1	2.5	1.9	1.1
Adults	Pt. Heiden	0.27	4.8	0.9	1.9	0.8
	Pt. Moller	0.41	4.8	0.9	2.1	1.1

x Juveniles which spend 1resp. 2 years in fresh water.
xx Fraction of the population passing through the three oilspill scenario areas.

the minor effect on smelt in terms of future (2 or 3 years later) fishing on returning adults.

The adults of total Bristol Bay sockeye salmon population might sustain a 5% mortality and an additional 2% tainting. Local disruption of salmon fishery might occur if a tanker accident of the unreal magnitude would occur during the peak salmon run (within about a month), especially if this occurred close to the fishing grounds.

5. LIST OF TECHNICAL REPORTS RESULTING FROM THE STUDY

(listed in chronological order of reproduction)

1. Kim, S. and A.W. Kendall.
   1983 (December). The numbers and distribution of walleye pollock eggs and larvae in the southeastern Bering *Sea.* NWAFC Proc. Rpt. 83-22, 35 pp.

2. Laevastu, T. and F. Fukuhara.
   1984 (March). Quantitative determination of the effects of oil development in the Bristol Bay region on the commercial fisheries in the Bering Sea. NWAFC Proc. Rpt. 84-06, 73 pp.

3. Pola-Swan, N.
   1984 (April). Biological impact of an oil spill (BIOS) model documentation. Part I: Fish migrations and exposure to contamination. NWAFC/REEST Prog. Dec. 21, 23 pp.

4. Gallagher, A.F.
   1984 (May). Documentation of the biological impact of an oil spill model (BIOS) . Part 2: Fish feeding and contamination through consumption - Subroutine FEDOIL. NWAFC/REEST Prog. Dec. 22, 21 pp.

5. Gallagher, A.F. and N. Pola-Swan.
   1984 (November). The uptake and deputation of petroleum hydrocarbons in marine species. A simulation study of the uptake and deputation of

petroleum hydrocarbons and its effects on selected marine species in the Bristol Bay ecosystem. NWAFC Proc. Rpt. 84-16, 68 pp.

6. Miyahara, R.K. and W.J. Ingraham.
1984 (December). Physical factors affecting the fate of a petroleum spill in the southeastern Bering Sea. NWAFC Proc. Rpt. 84-20, 65 pp.

7. Laevastu, T. and F. Fukuhara.
1985 (January). Oil on the bottom of the sea. A simulation study of oil sedimentation and its effects on the Bristol Bay ecosystem. NWAFC Proc. Rpt. 85-01, 53 pp.

8. Bax, N.J.
1985 (January). Simulations of the effects of potential oil spill scenario on juvenile and adult sockeye salmon (Oncorhynchus nerka) migrating through Bristol Bay, Alaska. NWAFC Proc. Rpt. 85-03, 128 pp.

9. Fredin, R.A.
1985 (February). Pacific cod in the eastern Bering Sea: A synopsis. NWAFC Proc. Rpt. 85-05, 58 pp.

10. Pola-Swan, N.B., R.K. Miyahara, and A.F. Gallagher.
1985 (April). Spatial and temporal extent of hydrocarbon contamination in marine species of Bristol Bay. NWAFC Proc. Rpt. 85-08, 40 pp.

11. Honkalehto, T.

1985 .(April), Recovery of three Bering Sea type fish populations from catastrophic larval mortality - simulation approach. NWAFC Proc. Rpt. 85-13, 35 pp.

12. Livingston, P.A.

1985 (April). Food habits of Bristol Bay species which might be affected by oil development. A study on the variability in demersal and pelagic food habits. NWAFC Proc. Rpt. 85-12, 39 pp.

13. Fukuhara, F.M.

1985 (May). Biology and fishery of southeastern Bering Sea king crab (Paralithodes camtschatica, Tiselius). NWAFC Proc. Rpt. 85-11, 170 pp.

14. Pola-Swan, N.B.

1985 (June). Modeling the biological impact of an oil spill; BIOS model. NWAFC/REEST Prog. Dec. 24, 51 pp.

15. Fukuhara, F.M.

1985 (July). Estimated impacts of hypothetical oil spill accidents off Port Moller, Port Heiden, and Cape Newenham on eastern Bering Sea yellow-fin sole. NWAFC Proc. Rpt. 85-15, 77 pp.

6. REFERENCES

Conan, G.

1982. The long-term effects of the_Amoco Cadiz oil spill. Phil. Trans. R. Sot. London, B297:323-333.

Connell, D. W. and G. J. Miller.

1980. Petroleum hydrocarbons in aquatic ecosystem - behavior and effects of sublethal concentrations: Part 1. CRC Critical Reviews in Environmental Control. 11(1):37-104. Part 2 ibid 11(2):105-161.

Davenport, J.

1982. Oil and planktonic ecosystems. Phil. Trans. R. Sot. London, B297:369-384.

Duval, W. S. and R. P. Fink.

1981. The sublethal effects of water-soluble hydrocarbons on the physiology and behavior of selected marine fauna. M.S. report EE-16 to Environment Canada. 86 pp.

Gearing, J. N. and P. J. Gearing.

1983. Suspended load and volubility affect sedimentation of petroleum hydrocarbons in controlled estuarine ecosystems. Can. J. Fish. Aquat. Sci. 40 (Suppl. 2):54-62.

Grahl-Nielsen, O., T. Neppelberg, K. H. Palmork, K. Westrheim, and S. Wilhelmsen.

1976. The Drupa oil spill, investigation concerning oil, water, and fish. ICES, CM 1976/E:34.

Järvela, L. E., L. K. Thorsteinson, and M. J. Pelto.
1984. Oil and gas development and related issues. In: L. J. Järvela [cd.] The Navarin Basin Environment and Possible Consequences of Planned Offshore Oil and Gas Development. NOAA and MMS.

Johnston, R.
1977. What North Sea oil might cost fisheries. Rapp. P.-v. Re'un. Cons. int. Explor. Mer, 171:212-223.

Kim, S. and A. W. Kendall.
1983. The numbers and distribution of walleye pollock eggs and larvae in southeastern Bering Sea. NWAFC MS rpt.

Liu, S. K. and M. J. Pelto.
(1984) Distribution of dispersed oil from a slick under stochastic weather states. (MS report, 16 pp.)

Monen, C. A. and M. J. Pelto.
1984. Transport and fate of spilled oil. In Proc. of the Synthesis Meeting: The North Aleutian Shelf Environment and Possible Consequences of Offshore Oil and Gas Development, NOAA and MMS, pp. 11-34.

Marchand, M. and M. P. Caprais.

1982. Suivi de la pollution de l'Amoco Cadiz dan l'eau de mer et les sediments marins. Amoco Cadiz, consequences d'une pollution accidentelle par les hydrocarburas. Cont. Natl. Explor. Oceans, paris: 23-54.

Malins, D. C. and 16 other coauthors.

1982. Sublethal effects of petroleum hydrocarbons and trace metals, including biotransformation, as reflected by morphological, chemical, physiological, pathological, and behavioral indices. MS Report, NWAFC, Env. Cons. Div. 268 pp.

McIntyre, A. D.

1982. Oil pollution and fisheries. Phil. Trans. R. Sot. Lend. B297: 401-411.

National Academy of Science.

1984. Petroleum in the marine environment.

Norges Offentlige Utrredninger NOCI 1980:25.

1980. Muligheter og konsekvenser ved petroleumsfunn nerd for 62°N.

Notini, M.

1976. Effecter av mineralolje pa littorala ekosystem. Tolte Nordiska Symposiet om Vattonforskning. Visby Mai 1976.

Payne, J. R., B. E. Kirstein, G. D. McNabb, J. L. Lambach, C. de Oliveira, R. E. Jordan and W. Horn.

1983. Multivariate analysis of petroleum hydrocarbon weathering in the subarctic marine environment. Proc. 1983 *Oil* Spill Conf. :423-433.

Payne, J. R. and B. E. Kirstein.

1985. Oil-weathering predictions (MS report, Science Appl. Inc. SAIC 5-85, 29 pp).

Disk:MEYER1 Docu:SumReport 11/21/85 mop

RU 643

EVALUATION OF THE EFFECTS OF OIL DEVELOPMENT ON THE COMMERCIAL FISHERIES IN THE EASTERN BERING SEA

(Summary Report)

T. Laevastu and R. Marasco
Project Leaders, and

N. Bax[1/], R. Fredin[2/], F. Fukuhara[2/], A. Gallagher, T. Honkalehto[1/],
J. Ingraham, P. Livingston, R. Miyahara, and N. Pola

Resource Ecology and Fisheries Management Division
Northwest and Alaska Fisheries Center, Seattle, WA 98115
and
1/ Compass Systems Inc.
2/ Natural Resource Consultants

November 1985

Minerals Management Service/National Oceanic and Atmospheric Administration

Interagency Agreement, IA - 14-12-001-30019